Investigating the Relationships Between Compost Maturity, Electrical Conductivity and Carbon Mineralization

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Background and Objectives

Compost can provide a rich organic nutrient source and soil conditioner for agricultural and erosion control applications. Compost maturity, however, is important to consider before using compost. Maturity is a term used to indicate compost suitability for plant growth (Benito et al., 2005). Many methods have been proposed for measuring compost maturity including compost respiration, electrical conductivity and plant assay germination (Epstein, 1997). Electrical conductivity measures the concentration of soluble ions or the salinity of the compost. Excessive salinity in compost can cause phytotoxicity directly, depending on the salt tolerance of the plant species. Salinity also can develop from nitrogen mineralization and production of organic acids. Plant assays can be especially beneficial for measuring compost maturity because they measure the compounded effects of various phytotoxic factors (Zucconi et al., 1981). Carbon dioxide respiration rate, equivalent to the carbon mineralization rate, may be a good indicator of compost maturity because high respiration can lead to nitrogen immobilization, anaerobic conditions, and the formation of phytotoxic compounds (Benito et al., 2005). The mineralizable carbon remaining upon amendment to soil, derived from the mineralization rate, may also be a good indicator of maturity because many phytotoxic compounds decompose with time (Zucconi et al., 1981). The objectives of this research were to:

(1) Investigate the relationship between plant assay germination, electrical conductivity and carbon mineralization of compost-amended soils, and

(2) Determine which of these compost properties are of most value in predicting compost maturity.

Methods

Compost and Soil Preparation

Food scrap and green material composts were obtained from Jepson Prairie Organics (Dixon, CA) in December 2004. The food scraps were collected from San Francisco and Oakland, CA's residential and commercial sectors. Food scraps were composted under intermittent aeration in Ag-Bags for 30 days and then placed in windrows, where composts were turned and watered twice a week for an additional 30 days. Green material was composted in windrows for 60 days. Finished composts were screened through a 9.5-mm trommel screen before collection. Soils included a Reiff very fine sandy loam collected from the UC Davis student farm and a professional potting soil (Schultz Professional Potting Soil Plus). The sandy loam was screened through a 3.18-mm sieve and stored dry at 4 ºC. Prior to experiments, materials were moistened to 50% of their water holding capacities by gradual addition and mixing of distilled water. The sandy loam was incubated at 50 ºC for 24 h to kill weed seeds. Materials were stored at –20 ºC until needed to prevent microbial activity.

Jepson Prairie Organics Food Scrap Composting

Compost and Soil Measurements

Compost and soil moisture content were measured via methods published by the US Composting Council (Thompson, 2004). Electrical conductivity (EC) and pH were measured according to VanderGheynst and coworkers (VanderGheynst et al., 2004). Water holding capacity was measured by saturating media, gravity draining for 24 h, and oven drying to estimate the moisture content of the saturated media. Respiration measurements were made on 30-g dry weight samples of soil and soil/compost mixtures in 250-ml containers aerated continuously with humidified air at 20 ml/min to avoid oxygen limitations, and incubated at 35 °C (Thompson, 2004). Carbon dioxide concentration was measured using an infrared CO_2 sensor (Vaisala, Suffolk, UK). Data were recorded every 5 h using a data acquisition system (VanderGheynst et al., 2002). Carbon dioxide evolution rate (CER) was calculated from a mass balance on each container. The total potential mineralizable carbon for each sample was determined by integration of the CER data (normalized by g total solids).

Respiration measurements also were made on soils amended with compost at 0% (soil control), 5% (representing field application), and 50% (representing horticultural application). Six hundred ml of mixtures were placed into heat-sealed bags aerated continuously with humidified air at 20 ml/min and incubated at 35 ºC (done in triplicate). Carbon dioxide concentrations were measured on the influent and effluent air every 5 h using a data acquisition system (VanderGheynst et al., 2002), and CER of the mixture ($CER_{Mixture}$) was calculated from a mass balance on each bag. These data and the total potential mineralizable compost carbon (Table 1) were used to calculate compost mineralization rate, $CER_{Compost}$ and potential mineralizable compost carbon remaining in the mixtures at any given time, C_R.

Mixtures were incubated for 8 (green material compost) to 10 (food scrap compost) days. Samples were taken from bags initially, at a middle time point (3-4 days), and at the end of the experiments. A plant assay and EC measurements were done at each time point.

Table 1. Selected properties of composts and soils

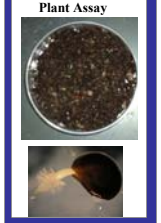
Sample	Water holding capacity (% dry basis)	pH	EC (ds/m)	Total potential mineralizable carbon (mg CO_2-C/g total solids)
Food scrap compost	208	5.5	6.65	390.3
Green material compost	178	8.1	1.63	110.7
Sandy loam soil	44.5	6.8	0.089	1.26
Potting soil	391	5.9	0.283	6.79

Aerated Bags with Compost & Soil Mixtures Inside Incubator

Plant Assays

Plant assays were performed using a direct-seed test of cress in soil/compost mixtures (Aslam and VanderGheynst, 2008). Forty-five ml of mixture were added to Petri dishes, with 20 seeds per dish, and 2 assays were conducted per bag for each sampling time. Water controls consisted of 3 ml of distilled water in Petri dishes lined with #1 Whatman filter paper. Petri dishes were sealed to minimize water loss and placed in an incubator at 22 ± 2 ºC with 10 h light/day for 5 days. Seeds were examined for germination, where germination was defined as any protrusion through the seed coat. Percent cress seed germination, normalized using germination in the water controls, was calculated for each sample.

Plant Assay



Experimental Designs and Statistical Analysis

Completely randomized designs were used in all experiments. Numerical integrations and nonlinear regression were performed using KaleidaGraph v. 3.6 (Synergy Software). Linear regressions were performed to determine if significant correlations existed between percent normalized germination and $CER_{Mixture}$, $CER_{Compost}$, C_R, and EC. Additional regressions were done to determine if EC was significantly correlated with $CER_{Mixture}$, $CER_{Compost}$, and C_R. Analysis of variance (ANOVA) was used to determine the significance of the correlations. JMP-IN v. 5.1 (SAS Institute, Inc.) was used to perform linear regressions and ANOVA.

Results

Cress germination in soil and compost mixtures incubated for 8–10 days significantly decreased with increasing electrical conductivity (P = 0.0014, Figure 1 and Table 2, Aslam et al, 2008). It has been reported in the literature that EC >2.45 ds/m is phytotoxic to cress (Sesay et al., 1997). Extracts from a 1/10 dilution of one soil/compost mixture exceeded and others were within 1 ds/m of this EC. EC was also significantly correlated with the carbon mineralization rate of the compost and soil mixture, $CER_{Mixture}$ (P=0.0001, r=0.81), the carbon mineralization rate of the compost by itself, $CER_{Compost}$ (P=0.0001, r=0.82) and highly significantly correlated with the remaining mineralizable carbon in the compost, C_R (P<0.0001, r=0.87) (Table 2). Since the soils were not leached during incubation, the results suggest that the initial elevated EC was due to ions associated with compounds present in the composts that decomposed or volatilized during incubation of the mixtures.

Soluble ions contributing to EC in extracts could have been from a variety of sources including inorganic salts associated with the soils and composts, volatile organic acids, ammonium and nitrate. Accumulation of nitrate is often a cause of phytotoxicity and it has been related to increases in EC (Smith and Doran, 1996). Although nitrate was not measured in this study, it could have been responsible in part for the increase in EC with compost amendment and mineralization. Volatile organic acids are common in immature food waste composts (Brinton, 1998) and the low pH of the food waste compost investigated here (i.e., 5.5) suggests the presence of organic acids. The pH of samples was well above the pKa of acetic, butyric and propionic acids (4.76–4.87) (Segel, 1976) (Figure 2), which are volatile organic acids common in composts (Brinton, 1998). Therefore most volatile organic acids would have been in a dissociated form and could have contributed to EC. If volatile organic acids volatilized or decomposed during incubation, the pH of the mixture should increase with time. The pH did tend to increase with incubation time for mixtures containing food scrap compost (Figure 2a); however, no consistent change in pH was observed for soils amended with green material compost (Figure 2b).

Further results showed that cress germination significantly decreased with increasing carbon mineralization rate of the compost-amended soil mixtures ($CER_{Mixture}$, P<0.0001, r=0.89), the carbon mineralization rate associated with the compost by itself ($CER_{Compost}$, P=0.0011, r=0.92) and the mineralizable carbon remaining in the compost (P = 0.0021, r = 0.91) (Table 2, Aslam et al., 2008). The decrease in germination could have been due to an increased production rate of phytotoxic compounds and the development of anaerobic environments. It could also have been associated with the phytotoxic compounds present in the compost that decomposed with time.

Figure 1. Electrical Conductivity vs. Percent Germination

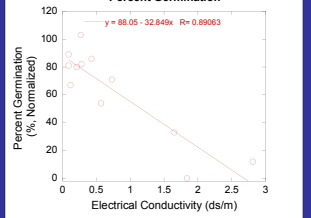


Figure 2a. pH vs. Incubation Time of Food Scrap Compost Mixtures

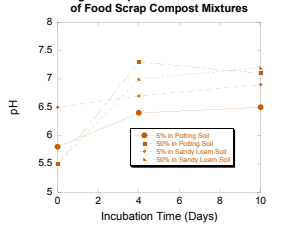
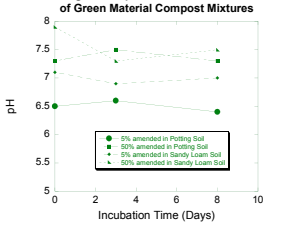


Figure 2b. pH vs. Incubation Time of Green Material Compost Mixtures



Conclusions

- Cress germination in soil and compost-amended soil mixtures decreased as electrical conductivity, carbon mineralization rate of the soil & compost mixture ($CER_{Mixture}$), carbon mineralization rate of the compost by itself ($CER_{Compost}$) and mineralizable carbon remaining in the compost (C_R) increased.
- Electrical conductivity was also significantly correlated with the carbon mineralization rate of the soil & compost mixture ($CER_{Mixture}$), the carbon mineralization rate of the compost by itself ($CER_{Compost}$) and highly significantly correlated with the mineralizable carbon remaining in the compost (C_R).
- The results suggest that phytotoxicity of the soil and compost mixtures was likely due to compounds associated with the electrical conductivity of the composts that were produced or present under high respiration rate conditions and that decomposed or volatilized during incubation of the mixtures.
- The correlations between the compost properties measured in this study were significant, suggesting that any of them could be used in predicting compost maturity when compost is amended in soil.
- While the change in pH during incubation was small in green material compost, pH dynamics in soils amended with food scrap compost could provide insight into possible mechanisms of phytotoxicity.

Table 2. Summary of measurements made on soil and soil/compost mixtures at the end of incubation at 35 ºC

Soil[a]	Incubation time (days)	Compost level and type[b]	EC (ds/m)	$CER_{Mixture}$[c]	$CER_{Compost}$[c]	C_R[c]	Percent Germination (%, normalized)
PS	10	0%	0.28	0.08			82
PS	8	0%	0.27	0.12			103
PS	10	5%FS	0.73	0.25	0.17	3.4	71
PS	8	5%GM	0.43	0.22	0.11	0.8	86
PS	10	50%FS	2.81	2.00	1.96	39.3	12
PS	8	50%GM	1.65	1.15	1.09	7.30	33
SLS	10	0%	0.09	0.08			81
SLS	8	0%	0.09	0.09			89
SLS	10	5%FS	0.21	0.18	0.11	3.40	80
SLS	8	5%GM	0.12	0.21	0.13	0.90	67
SLS	10	50%FS	1.84	1.72	1.68	38.0	0
SLS	8	50%GM	0.57	1.05	1.01	8.10	54

[a]PS = Potting Soil and SLS = Sandy Loam Soil

[b]FS = Food Scrap Compost and GM = Green Material Compost

[c]$CER_{Mixture}$ = mineralization rate of soil/compost mixture (mg CO2-C/day/ml)

, $CER_{Compost}$ = mineralization rate of the compost by itself (mg CO2-C/day/ml), and C_R = mineralizable carbon remaining in the compost (mg CO2-C/ml)

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